The Synthesizer: a versatile active learning tool for electrical engineering

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ABSTRACT

This paper presents a project-based course for Electrical Engineering (EE) freshman students, that is based on a modular analog synthesizer. The project topic creates high motivation and lends itself to basic EE concepts and skills, to which students are introduced gradually as they build the electronic modules collectively with the teachers' guidance. Once the basic modules are built and tested, interesting sound effects can be created while understanding the relationship between the different circuit parameters and the sound characteristics. This creates good conditions for an intuitive exploration of abstract concepts like time-domain, frequency-domain, frequency-spectrum, filtering, etc. Finally, students are presented with the challenge of creating a controller to play the synthesizer as a musical instrument. The results after our first experience are very positive, both in terms of students' motivation and achievement.

Keywords: interdisciplinary courses, tools for active learning, electronics and music

Session Type: poster session

Introduction

A synthesizer is an electronic instrument that can generate a wide range of sounds, used extensively from the 60's to the 80's by artists from diverse musical styles. The synthesizer consists in several modular circuits (voltage-controlled oscillators, noise generators, voltage-controlled amplifiers, voltage-controlled filters, envelope generators, low-frequency oscillators, etc.) that can be creatively assembled and controlled in order to get different sound effects. Here, we present it as a versatile active learning tool for electrical engineering students, bridging music and electronics.

Teaching electronics for freshmen can be a daunting task. They arrive from high-school expecting to find in the university amazing technical projects related with electrical engineering. However, they can easily lose their enthusiasm if they start learning the complicated physics behind electronics components, such as diodes and transistors, or mathematical theory that will later be applied to circuit analysis.

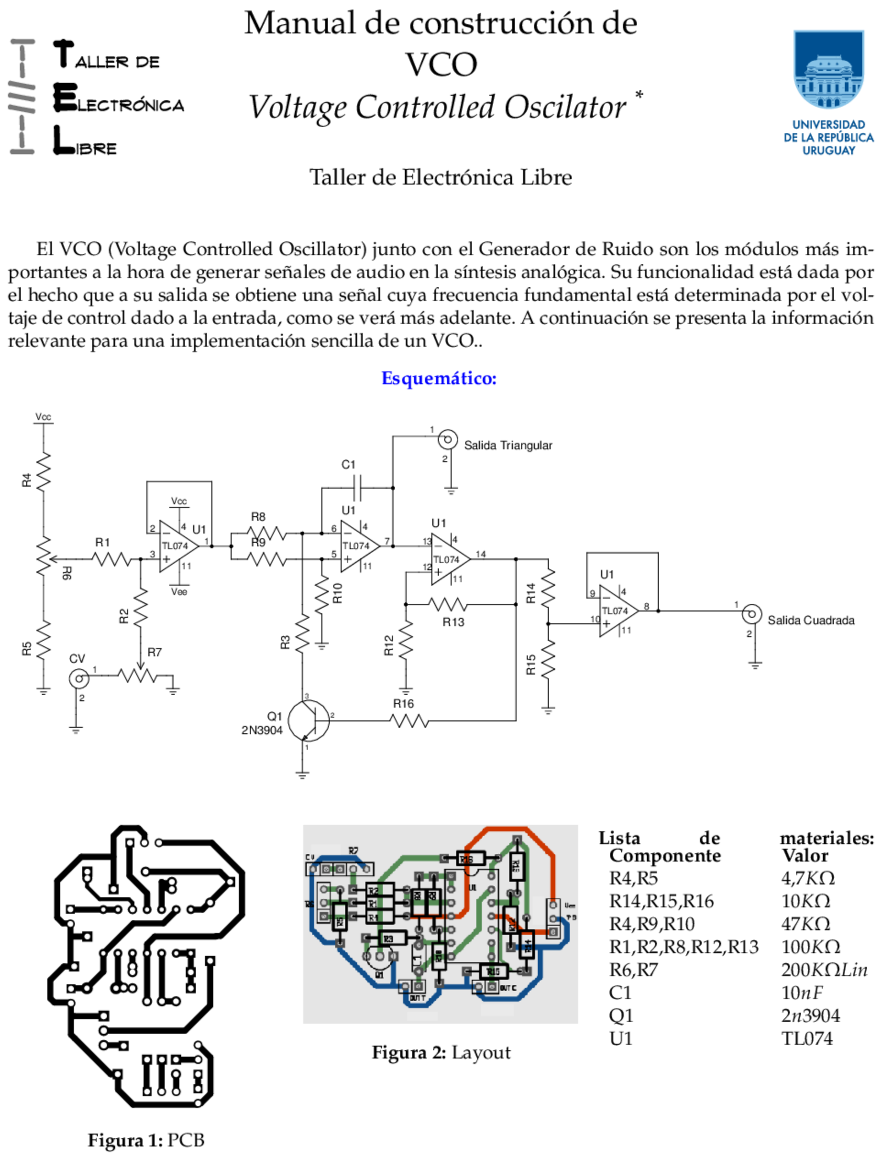
In order to boost their motivation towards the career, hands-on methodologies are used in some universities, enabling students to work with digital circuits, robotics, etc. These projects usually involve high-level tasks, like micro-controllers programming or systems integration, but almost no low-level manipulation, given their complexity.

With the purpose of including low-level technical skills, we propose to use the synthesizer as the core of a hands-on subject on practical electronics for freshmen, based on open source resources (Bermúdez, 2013). Music synthesis is reported in the literature as a topic for introducing students to engineering concepts, but mostly digital (Douglas, 2001, Marpaung et al., 2011). We could only find one example of using analog synthesizers as a teaching tool (Billis et al., 2011).

Methodology

The course is organized as follows. First, students learn to recognize basic electronic components (resistors, capacitors, transistors, operational amplifiers), and are introduced to some basic blocks useful for an understanding of the principles of operation of different circuits (e.g., voltage-to-current converters, Schmitt triggers, etc.).

Next, students are divided in groups of six for the purpose of developing the projects. They are provided with handouts (see figure 1) containing the information needed to build each module: a brief description of the circuit function, schematics, PCB layout, bill of materials, and an overview of the circuit operation. In order to allow an active participation of every member in the construction of the modules, the groups of six are subdivided in groups of three. It was concluded that this was the optimal group size for learning the techniques and procedures involved in a practical implementation of an electronic circuit.



Manual de construcción de
VCO
Voltage Controlled Oscilator *

Taller de Electrónica Libre

El VCO (Voltage Controlled Oscillator) junto con el Generador de Ruido son los módulos más importantes a la hora de generar señales de audio en la síntesis analógica. Su funcionalidad está dada por el hecho que a su salida se obtiene una señal cuya frecuencia fundamental está determinada por el voltaje de control dado a la entrada, como se verá más adelante. A continuación se presenta la información relevante para una implementación sencilla de un VCO..

Esquemático:

Figura 1: PCB

Figura 2: Layout

Lista de Componente	materiales: Valor
R4,R5	4,7$K\Omega$
R14,R15,R16	10$K\Omega$
R4,R9,R10	47$K\Omega$
R1,R2,R8,R12,R13	100$K\Omega$
R6,R7	200$K\Omega Lin$
C1	10nF
Q1	2n3904
U1	TL074

Figure 1. First page of a handout example for the VCO module, with a brief introduction of the circuit, its schematics, PCB layout and bill of materials.

An outline of the process is described next. The layout of the PCB is transferred to a copper clad board (FR-2 or FR-4) manually with a permanent ink marker. The PCB is etched with ferric chloride under the supervision of the teachers; this process gives the opportunity to describe basic safety and environmental procedures. The etched board is drilled manually for thru-hole components. The final step is to populate and solder the discrete components onto the PCB; again, during the process the teachers describe the basic soldering techniques and safety procedures.

They start by assembling a voltage-control oscillator (VCO), that generates square and triangular waveforms whose frequency can be controlled by an external voltage input (control voltage, CV). Although the circuit is quite complex for the students, they are encouraged to understand it block by block, and using analogies with other physical systems. The circuit is tested by connecting it to an amplifier that feeds a speaker and looking at the waveforms with an oscilloscope, allowing them to discuss and consolidate concepts that they learn at high-school, such as time and frequency.

Then, students assemble and test more modules: voltage-controlled amplifiers (VCA) and filters (VCF), noise (NG) and envelope generators (ADGen), etc., with increasing autonomy. Each device not only enhance the range of sound behaviours, but also serves as a base to work with some concepts, like noise, filtering, frequency spectrum, amplification, saturation, etc.

At the middle of the semester, each team presents to the class an example of operation of the whole synthesizer, generating and performing a sound effect by interconnecting the different modules in a creative way. They also have to present a written document, explaining how to use the modules built.

Some basic interconnections can be used as an example to foster the understanding of more abstract concepts. For example, Fig. 2 shows module configurations for vibrato and tremolo effects, which can be related to data transmission concepts like frequency modulation and amplitude modulation respectively. This creates an opportunity for teachers to introduce these and related concepts in an intuitive way, before they are presented formally to the students later in the curriculum.

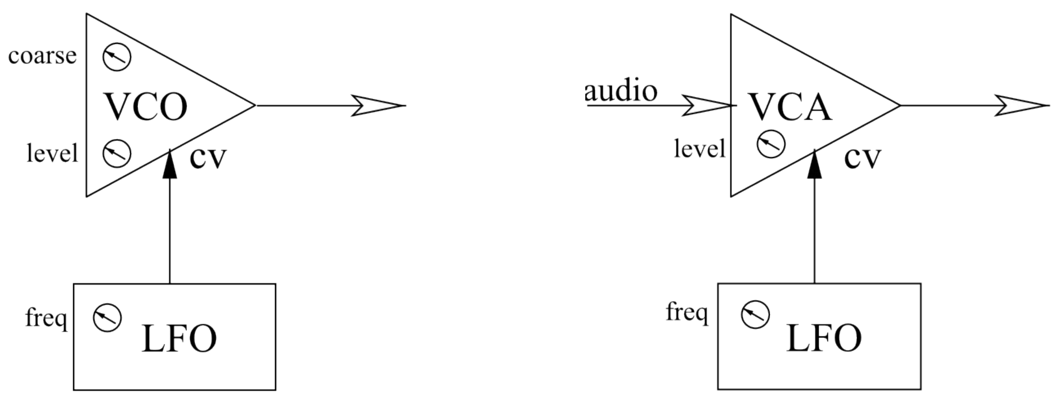


Figure 2. Basic interconnections of the synthesizer modules. Left: vibrato (frequency modulation), right: tremolo (amplitude modulation).

The second half of the semester is devoted to the development of a controller that will be used to play the synthesizer as a musical instrument. This is the most challenging part of the subject, because students have a large degree of autonomy to conceive and design their controller, with time as the only constraint. Although crazy ideas are accepted and even encouraged, it is important that students understand the role of the controller in the synthesizer, as a physical interface with the musician for manipulating the operation of the electronic modules with a musical intent, allowing a specific kind of artistic expression.

The students are presented with some transducers (e.g., phototransistors, light-dependent resistors, potentiometers, electret microphones, etc.) and basic blocks (e.g., triggers, impulse detectors, comparators, DC motors, etc.), and are also encouraged to discuss their own ideas with the teachers. The interaction of the group members internally, with the teachers and with other groups, shapes the creative process that evolves with freedom but with technology constraints, until a definite idea is reached and implemented. The result is a device that allows a tangible interaction with the synthesizer modules, translating the musician stimulus into control voltages (CV).

Thanks to the collaboration of a teacher from the School of Music of the University, some groups are able to improve their designs, using inputs from another point of view. For example, a group had decided to work with light sensors that generate sounds, but not in an harmonic way. A more “musically acceptable” controller design would be too complex for them. However, after presenting their case to the music teacher, he showed them a non conventional form of music, based on a twelve-tone system, enabling them to understand their controller under new musical criteria.

The outcomes of each project are presented by them in the final session.

Results

Some of the controllers developed by the students are:

- laser harp: it is based on coupled pairs of lasers and phototransistors, being activated when a light beam is interrupted, generating a note according to the well-tempered scale (Fig. 3).

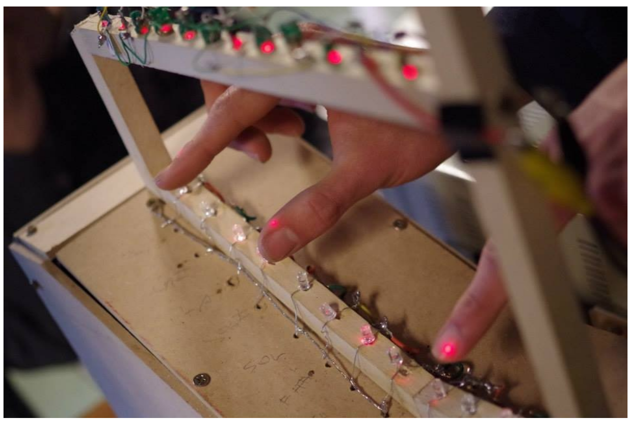


Figure 3. Laser harp

- ribbon: a steel string is placed above a resistive ribbon (extracted from a VHS tape), only being in contact when a player pushes the string and generates a control voltage (due to the voltage divider) for the VCO, as well as a trigger that activates an envolope for the VCA (Fig. 4).

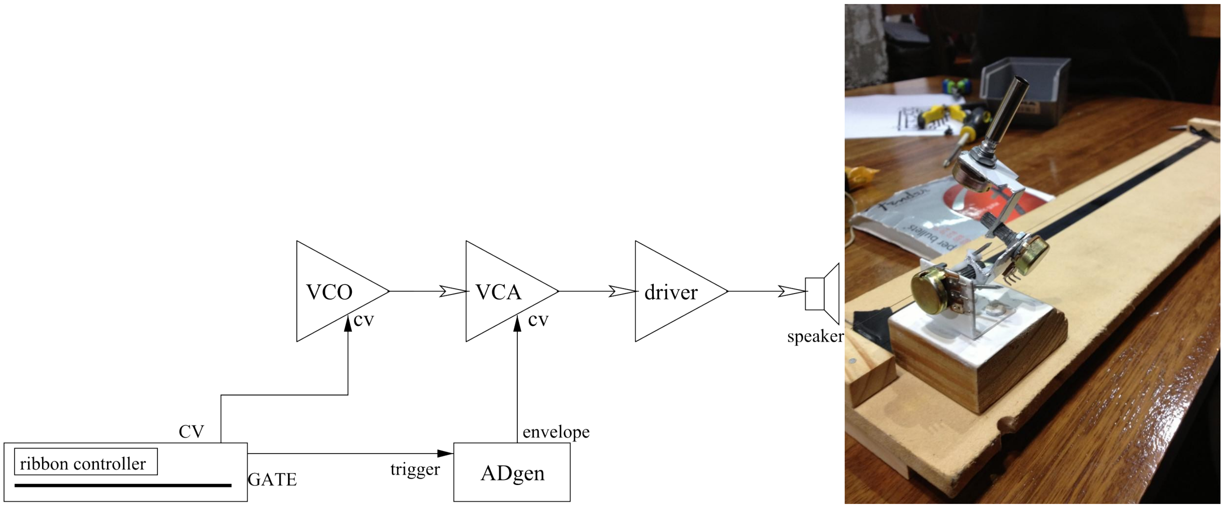


Figure 4. Ribbon controller. Left: block diagram. Right: photograph.

- carousel sequencer: the instrument uses an array of phototransistors equally distributed on a circumference, that are activated by three LEDs equally distributed on another rotating circumference driven by a DC motor; as the motor spins, the phototransistors are activated sequencially, generating different notes that are configured with a bank of switches. The rotation of the DC motor is controlled by an envelope generator triggered by a clap detector, thus creating a rich sound sequence every time hands are clapped (Fig. 5).

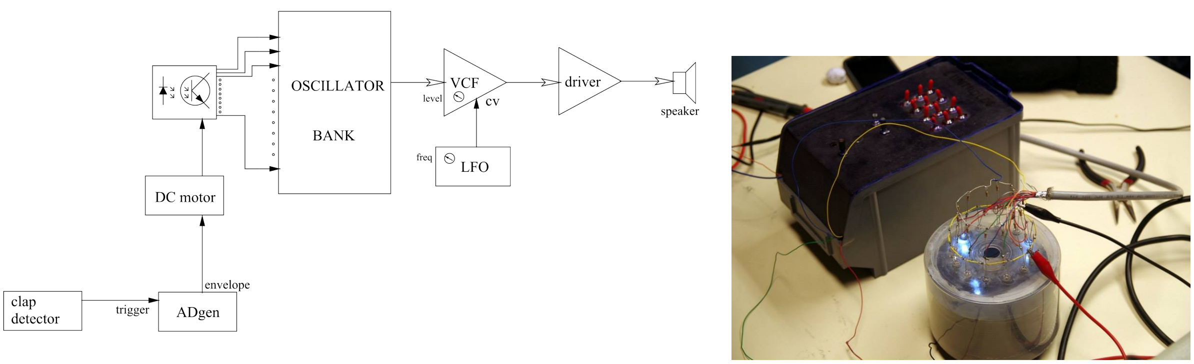


Figure 5. Carousel sequencer. Left: Block diagram, right: photograph.

- telephone keyboard: the classical keyboard controller is implemented with a twist, since a recycled telephone keyboard takes the place of traditional black and white keys; the resulting instrument resembles somehow a bandoneon because of the peculiar key arrangement.

- guitar-shaped signal router: pairs of lasers and phototransistors mounted on a guitar-shaped board are used to route the synthesizer’s signals, so different module interconnections and parameters can be selected with the fingers, generating a changing combination of sounds.

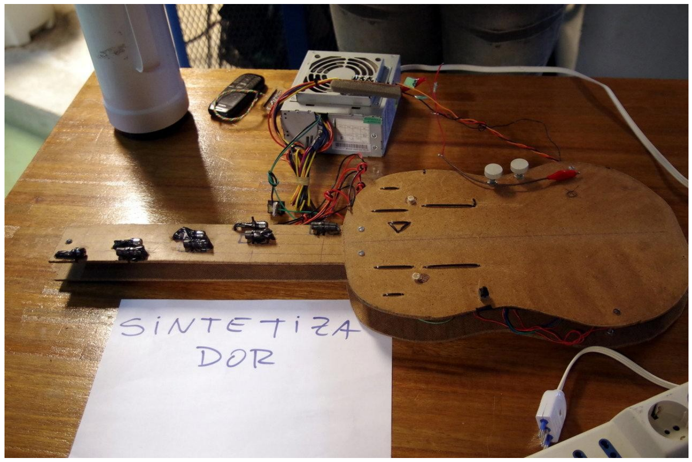


Figure 6. Guitar-shaped signal router.

- coupled sequencers: this project uses two coupled sequencers, each generating an independent set of CVs that are added to create the CV for the VCO; since one of the sequencers' tempo is a fraction of the other's, interesting transposed arpeggio sequences are generated.

Conclusions

The main advantages of using the synthesizer within the electrical engineering curriculum are:

- Modularity: students can build, understand and test it by stages; they can build only the basic modules (VCO, VCA, VCF, NG and ADGen) or add more to enhance the range of possible sounds.More advanced students can even design new and more complex modules.
- Low barriers to entry: the skills and tools needed for building and testing each module are very basic and don't require previous experience.
- High ceiling: while it is possible to create an interesting musical instrument with basic skills, there are endless opportunities to improve the design with more complex modules that require advanced electronics concepts, and so students can continue the development in later stages of their studies.
- Low cost: only standard electronics components and tools are needed. A special workspace is not required: students can even work in their own homes.
- High satisfaction: the synthesizer is a real musical instrument that can be played by controlling electrical signals, enabling students to link electronic operation with sounds; they can also demonstrate it to non-technical public, such as their friends and families, boosting their motivation.
- Direct links with other subjects: from the first class, students learn to manipulate and understand electronic components that they study theoretically in physics subjects; besides that, they can link musical concepts such as tremolo and vibrato with their corresponding signal modulations (amplitude and frequency), widely used in engineering applications.
- Interdisciplinary: music students can also participate of synthesizer workshops, learning from engineering students how it works and providing

new ideas on how to assemble and play it; conversely, engineering students can learn from their music counterparts.

Figure 7. Workshop with a music teacher.

According to our experience, the synthesizer can be used as an active learning tool for a wide range of electrical engineering students. Freshmen learn practical electronics by building the basic modules and controllers, whereas more advanced students can develop complex modules for special musical effects. In all the cases, students also develop design and project management skills, by going from the idea of new controllers and modules to their design and testing.

Figure 8. Students after the final session.

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